APPENDIX D

CLEAN VERSION OF THE AMENDED PARAGRAPHS OF THE SPECIFICATION

The first and second full paragraphs on Page 14 of the Specification:

The well known neutron induced fission reaction is the preferred source of nuclear energy because of its high energy yield and its ability of sustaining a chain reaction based on neutrons. In this reaction, the initial nucleus is split into two fission fragments (FF) and a number of neutrons (≥ 2) which are necessary to continue the chain reaction. The average energy sharing in a typical fission reaction is such that a major proportion – namely 168 MeV/191 MeV = 88 % - of the usable energy (neutrinos are excluded) is produced in the form of kinetic energy by the pair of FF. The fragments of father nucleus being split away beyond the range of the (attractive) nuclear forces, energy is produced by the strong electrostatic repulsion between the two fragments - the rest being de-excitation of the nuclear levels with gamma and neutron emission, possibly followed by β de-excitation.

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FF travel a very short way in the fissionable fuel, delivering energy in the form of heat in the immediate vicinity of the father nucleus, with an extremely high specific ionization losses due to their large charge. The longest range of each of the two FF being typically ≤ 10 μm in a metallic fuel, such a strongly localized energy deposition is generally not directly accessible and the high specific heat deposition of the FF is diluted by thermal conductivity within the bulk mass of the fuel.

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The third full paragraph on Page 15 of the Specification:

Such high temperature is transformed by the nozzle into a jet of atomic hydrogen of high speed, namely a specific impulse $I_{sp} \approx 2{,}000$ s, much larger than $I_{sp} \leq 430$ s of the best chemical engines. A required final rocket speed can be achieved with a substantially smaller mass of propellant, which in turn extends the potential range of the journey or, alternatively, shortens its duration.

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The first full paragraph on Page 18 of the Specification:

After a fast slowdown process in the reflector, the average (fission produced) neutron kinetic energy will quickly approach the thermal energy at the temperature of the reflector. A simple calculation based on diffusion theory for thermalised neutrons shows that, for the idealized fuel configuration, the flux in the presence of the (infinite) reflector is enhanced with respect with the one without reflector approximately by the factor

$$F = \frac{1}{\kappa D} = \sqrt{\frac{3\Sigma ela}{\Sigma capt}}$$

where Σ_{ela}, Σ_{capt} are respectively the elastic and capture cross sections of the diffusing material. Some candidate elements are listed in Table 2. Low A elements have been chosen, since they ensure a fast thermalization of the fission produced neutrons. The quantity $D = \Sigma_{ela}/3$ is the so-called diffusion coefficient and $1/L = k = \sqrt{\Sigma_{capt}}/D$ is the diffusion parameter. More complicated chemical compounds, containing elements with

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small neutron capture macroscopic cross sections can also be used. We note that oxygen has such properties: for instance the properties of the BeO are very close to the one of metallic Beryllium.

The third full paragraph on Page 20 of the Specification:

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The nuclear properties of ^{242m}Am ($t_{1/2}$ = 141 y) are briefly summarized, having in mind the likely destination of the described engine, i.e. propulsion in space. The main decay mode (99.95%) is a transition to the ground state ^{242}Am ($t_{1/2}$ = 16.01 h) by internal conversion with the emission of a soft electron (40.3 keV), the rest being β -decay. The daughter nucleus decays 17.3 % into ^{242}Pu (tl/2 = 3.76 x 10^5 y) and 82. 7 % into ^{242}Cm ($t_{1/2}$ = 162. 9 d), which in turn by α-decays transforms into ^{238}Pu ($t_{1/2}$ = 87.72 y).

The second full paragraph on Page 34 of the Specification:

A13 Cont.

A correct analysis of the heating process requires a coupled hydrodynamic and FF propagation numerical calculation, which has been performed with the geometry of Figure 5 and a final temperature of 9400 °K (radiation limited, see later on). The tube diameter has been set to 40 cm and the tube length to 250 cm. However the ratio size/pressure is an excellent scaling parameter in order to extend the result to different tube diameters. As long as the length is much greater than the tube diameter, the energy distribution in the central part is uniform and independent of the tube length. The power density emitted by unit area has been set to A = 200 Watt/cm^2. We note that even for

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such a relatively modest value of A the specific energy deposition dW/dm $\approx 10^6$ Watt/g in the gas is very large indeed. The resulting distribution (Figure 12) show that dW/dm is relatively uniform, as predicted by one dimensional model, provided the pressure is adjusted to match the range of the FF to the diameter of the tube. For pressures much lower than the optimal one a significant fraction of the FF hit again the walls of the tube. For much larger pressures, FF stop before reaching the central part of the gas.

The second full paragraph on Page 35 of the Specification:

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To conclude, for a relatively modest surface nuclear power density of the foil of A = 200 W/cm^2, the specific, volume averaged power given to the gas is dW/dm $\approx$0.661 MWatt/g, very large indeed.

The first full paragraph on Page 53 of the Specification:

A15 Cont.

The actual dependence for typical values of the specific fission power is shown in Figure 22. It is evident that in order to ensure an effective cooling, the radiator must operate at the highest possible temperature. A good reference value could be the boiling point of Lithium at low pressure (1 bar absolute) corresponding to 1342 °C. At this temperature the ratio S_{rad}/S_{foil} is respectively 5.12, 2.56 and 1.28 for dW_{fiss}/dS_{foil} = 200, 100 and 50 W/$_{cm}$2 which are reasonable values. The latent boiling heat of Li^7, which is likely to be exploited for the cooling (boiling reactor concept) is 19.24 kJoule/g (134.7

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kJoule/mol) and cooling for instance a 100 MWatt power requires boiling and subsequent condensation of a mere 5.2 kg/s (9.7 litre/s) of coolant. Therefore, for the sake of the qualitative considerations which follow, we shall assume an indicative temperature of the engine of ≥1,500 °K.